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Owing to shortage of funds, discovered after the paper was accepted and this abstract printed, the U. S. Department of Agriculture has greatly reduced the number of pages in the Journal of Agricultural Research. The number in which the paper of which this bulletin is a summary will not be distributed until the late fall of 1919. All bibliographical references should be to the full paper and to the Journal of Agricultural Research and not to the bulletin.

Maine Agricultural Experiment Station

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BULLETIN 279 APRIL, 1919

THE VARIATION OF THE MILK OF AYRSHIRE COWS IN QUANTITY AND FAT CONTENT OF THEIR MILK.

CONTENTS

This paper is a summary of an extensive paper with the same title published in the Journal of Agricultural Research. This is one of several similar investigations that are fundamental to the main problem of the inheritance of milk production. These physiological studies describe for the first time the relative influence of environment and heredity in causing milk flow. The important law of change in quantity of milk with age is given in bold face type on page 62.

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* Absent on leave during period of war.

BULLETIN 279

THE VARIATION OF AYRSHIRE COWS IN THE QUANTITY AND FAT CONTENT OF THEIR MILK[1]

Raymond Pearl and John Rice Miner

The present work has for its purpose a biometrical analysis of the normal individual variation in the milk flow and the fat content of the milk in Ayrshire cattle.

The investigation was undertaken because of a strong conviction that a fairly comprehensive knowledge of the normal variation of a character which is to be made the basis of inheritance studies is essential if such study is to be critical. This viewpoint is entirely independent of any position which one may hold regarding the significance of different kinds of variation. As a matter of biological fact one never deals actually with one sort of variation absolutely free from the influence or effect of all others. For, even though we may be studying a discontinuous variation of strictly germinal origin and control, there will be, in the actual somatic expression of this variation, a super-imposed fluctuating variation of non-germinal origin.

These considerations become particularly significant when the character dealt with is one especially subject to environmental influences, in consequence of which the fluctuations assume highly significant proportions in relation to the underlying germinal differences. Such characters are, for example, fecundity, fertility, and, to a marked degree, milk production in cattle. Any milk or fat record represents the result of the action of a complex of factors, of which those classed broadly as environmental certainly play a very important part. To arrive at any sound conclusions regarding the inheritance of these characters it will be essential to form some sort of judgment as to the proportionate parts which genetic and environ-

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[1]This paper is a resumé of an extensive technical paper with the same title published in the Journal of Agricultural Research.

mental factors play in the production of particular, individual records. It seems perfectly clear that a prerequisite to anything approaching a sound basis for such a judgment is a thorough analytical study, with the best of biometric tools, of the normal variability of milk and fat production.

MATERIAL

The present study is based on the records of Ayrshire cattle published in the Reports of the Ayrshire Cattle Milk Records Committee of Scotland, compiled by Speir and Howie.[2] Portions of the very valuable records gathered by this Committee have been used by other students of the problems of milk production, notably Wilson, Pearson, and most recently Vigor.

The reports under consideration include, so far as it is possible to get the information, the following items:

1. Total milk produced (in gallons).
2. Average percentage of fat, determined from periodic tests.
3. Total milk calculated to a 3 per cent fat basis.
4. Weeks in milk.
5. Age of cow.
6. Date of last calving.
7. Miscellaneous information about the cow, particularly of abnormal circumstances of any sort during the test.

In the present study all available records from the 1908 and 1909 Reports have been used, if they came within the following regulations which we established in order to secure critical material for variation study.

a. The record must be complete in all particulars, (i. e., cover items 1 to 6 in the list above).
b. The record must be based on 32 or more weeks in milk.
c. There must be nothing of an abnormal or unusual nature about the cow or the lactation, so far as discoverable from the records.

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[2]It is a great pleasure to acknowledge, with grateful thanks, the kindness of Mr. John Howie of Ayr, Scotland, the Secretary of the Milk Records Committee, in furnishing a set of the Committee's Reports for this investigation.

The two characters dealt with in this study are (a) average milk yield per week in gallons, and (b) average fat percentage. The values for the former were obtained by dividing the total yields as given in the Reports by the weeks in milk. The fat percentage figures were taken directly from the Reports. The ages were taken as centering at the mid-point of each year. That is, for example, all cows recorded at 3 years or more in age, but less than 4 years were put in the 3-year class in the tables of the present paper. A 3-year old hence is to be taken as including anything between 3 and 4 years.

The Comparative Variability of Milk Production

Milk production is essentially a physiological character. It is a matter of some interest and significance to examine the variability of the character in comparison with other physiological characters, and also with some that are more strictly morphological, as, for example, bone measurements. Such comparisons may be made through coefficients of variation. It must, however, always be kept clearly in mind just what a coefficient of variation is, and care must be taken to avoid drawing too sweeping or even entirely unjustified conclusions from comparison of these constants. What the coefficient of variation measures is the percentage which the "scatter" or variation exhibited by a distribution as measured by the standard deviation, is in the mean of the character varying. For some purposes this percentage is meaningless.

In Table 1 (page 62) are given coefficients of variation for a number of characters for purposes of comparison with milk yield. The coefficients are arranged in order of descending magnitude.

This table brings out the well-known fact, which has been discussed in some detail by Pearl, Gavin, and others, that, in general, physiological characters exhibit high coefficients of variation as compared with strictly morphological characters. Characters which are intermediate in their quantitative determination, as, for example, the length of the egg in the domestic fowl, give coefficients of variation intermediate in value. Purely physical characteristics which are usually regarded by physicists and chemists as "constants," such as the specific gravity of eggs, show very low coefficients of variation.

It is of interest to compare the coefficients of variation for total yield and absolute amount of fat in the mixed milk of a large herd with those for milk yield as discussed in the present paper. It is seen that the former are about 9, whereas the coefficients for milk yield give values of about 17 to 25, depending upon whether cows of all ages or of a single age are considered.

In the case of secular variation in the amount of quality of the mixed milk of a large herd, individuality of the animal as a source of variation is entirely eliminated. The observed variation must there be due to the combined action of all the external environmental influences which affect in greater or less degree the milk yield of every cow.

On the other hand, the constants of variation for milk yield determined in this paper are based upon the diversity or variation exhibited among a large number of different cows in respect of weekly yield. Here one primary factor in the causation of the observed variation must be the individuality of the animal in respect of milking ability. By individuality in this sense is meant the genotype of the individual with regard to the character named. But in the causation of the variation in milk yield as here discussed there must be involved the combined influence of the individuality of the animal *plus* that of all the environmental factors which act in producing variation in the mixed milk of the herd, since each of these causes influence every individual animal while it is making its individual record.

It is, therefore, possible to make comparison here between observed variations (as measured by the coefficient) due, on the one hand, to environmental influences alone, and, on the other hand, to genotypic differences plus environmental influences. The differences should represent that part of the observed variation due to genotypic differences.

The figures as they stand suggest that roughly about one half of the variation (measured by the coefficients of variation) in milk yield results from the varying genotypic individuality of the animals in respect of this character, and the other half results from the varying external circumstances to which cows are subjected during lactation and which have an effect upon the flow of milk. Or, to put the matter in another way,

if the conclusion just stated were true it would mean that if a large number of cows were placed in environmental circumstances which were at once ideal and uniform we should expect the variation exhibited in milk production to be roughly about one-half of that which we actually find when we measure this variation under ordinary circumstances.

In the case of fat content of milk, individuality has clearly much more to do with determining variation. Here the effect of the environment is extremely small.

TABLE 1.

Coefficients of Variation for Various Characters.

Characters	Coefficient of Variation	Authority
Number of children per family (New South Wales)	48.41	Powys
Area of comb (Domestic fowl)	39.97	Pearl and Pearl
Weight of spleen (English males)	38.21	Greenwood
Size of litter (Mouse)	37.50	Weldon
Lambs per birth (Sheep)	35.78	Pearl
Dermal sensitivity (English males)	35.70	Pearson
Annual egg production (Domestic fowl)	34.21	Pearl and Surface
Size of litter (Poland-China swine)	27.41	Surface
Size of litter (Duroc-Jersey swine)	26.09	Surface
Milk yield (Total lactation)	25.78	Gavin
Milk yield (Daily average)	25.72	Gavin
Fecundity* (Horse)	24.77	Calculated from data of Pearson
Heart weight (English males)	22.22	Greenwood and Brown
Weight of kidneys (English males)	21.05	Greenwood and Brown
Weight of liver (English males)	20.82	Greenwood and Brown
Swiftness of flow (English males)	19.40	Pearson
Body weight (English males)	18.91	Greenwood and Brown
Rev. maximum daily milk yield (For given age)	17.998	Gavin
Weekly Milk Yield (Ayrshire cattle)	*17.08*	*This paper*
Breathing capacity (English males)	16.60	Pearson
Strength of pull (English males)	15.00	Pearson
Weight of shell of egg (Domestic fowl)	13.86	Curtis
Body weight (Domestic fowl)	12.66	Curtis
Weight of albumen of egg (Domestic fowl)	12.27	Curtis
Length of red blood corpuscles (*Bufo* tadpoles)	11.85	Pearson
Weight of yolk of egg (Domestic fowl)	11.31	Curtis
Amount of fat in mixed milk (Daily fluctuations)	9.68	Pearl
Yield of mixed milk (Daily fluctuations)	9.05	Unpublished data in this laboratory
Fat percentage of milk (Ayrshire)	*8.81*	*This paper*
Weight of egg (Domestic fowl)	8.36	Pearl and Surface
Brain weight (Bavarian males)	8.12	Pearl
Length of forearm (English males)	5.24	Pearson and Lee
Length of femur (French males)	5.05	Pearson
Length of egg (Domestic fowl)	4.24	Pearl and Surface
Stature (English males)	3.99	Pearson and Lee
Horizontal circumference of skull (English males)	2.87	Macdonell
Specific gravity of egg (Domestic fowl)	0.50	Pearl and Surface

*Fecundity here means the fraction which the actual number of offspring arising from a given number of coverings is of the possible number of offspring under the circumstances.

THE RELATION OF MILK AND FAT PRODUCTION TO AGE

With the analyzed variation data furnished by this study, it is possible to consider the problem of the changes in milk production per unit of time and in mean fat percentage, with advancing age of the cow. The great importance of a thorough and comprehensive knowledge of these relationships, if one is to make any adequate investigation of the inheritance of milk and fat production is sufficiently obvious. It is a perfectly well known fact, incorporated in all rules for advanced registry of dairy cattle, that milk production does change with age, and to a marked degree. Until investigations on this subject were undertaken in the Biological Laboratory of the Maine Station some years ago it has always been assumed by those (such as advanced registry officials) who have had to deal with the problem that the changes of milk production with age were linear up to "mature" age, usually taken as 5 years, and that after that time there was no further change with advancing age. How far wrong such an assumption is will be shown below. It was pointed out four years ago by Pearl in a preliminary paper based on calculations then completed that the fundamental law of change with milk flow with age is logarithmic.*

Let us now examine the facts for Ayrshires, considering first mean weekly yield. The mean weekly yields in gallons for the combined distributions from age 2 to age 16 inclusive are exhibited in Table 2. The calculated values are those given by a logarithmic curve, of which the equation is

$$y = 12.4766 + .6146x - .0366x^2 + 3.6641 \log x$$

where y denotes mean weekly yield in gallons and x age in years, taking origin from 1 year.

It is very evident from Table 2 that the change here is logarithmic. No better agreement between observation and theory than that here shown could be expected. The law of change may be stated in words in the following way. **In these Ayrshire cattle the absolute amount of milk produced per unit of time increases with the age of the cow until a maximum is**

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*See Bulletin 262 this Station.

reached, but the amount of increase diminishes each year with advancing age until the absolute maximum of production is reached. After the time of maximum productivity the absolute production per unit of time decreases with advancing age, and by a continually increasing amount.

TABLE 2.

Comparison of observed mean weekly yields at different ages with those calculated on the assumption that the change is logarithmic

Age in years	Observed mean weekly yield	Calculated mean weekly yield
2	13.610	13.055
3	13.841	14.656
4	15.230	15.730
5	16.463	16.544
6	17.470	17.183
7	18.049	17.684
8	18.260	18.067
9	18.556	18.344
10	18.738	18.524
11	18.111	18.610
12	18.457	18.608
13	18.750	18.519
14	17.950	18.346
15	18.131	18.071
16	17.875	17.754

With the equation relating to mean weekly yield and age in hand we may consider the important problem of the age at which milk production is at a maximum in these cows. To get an answer to this question we have obviously only to equate $\frac{dy}{dx}$ to zero and solve for x.

We have

$$\frac{dy}{dx} = .6146 - .0732x + \frac{1.5913}{x}$$

When

$$\frac{dy}{dx} = 0, \text{ we have}$$

$$x = 10.4720$$

Or, we may say that in the large group of cows here dealt with the maximum rate of milk production per unit of time is only reached when the cow is $11\frac{1}{2}$ years old.

Turning next to the relation of fat percentage to age we have the essential data exhibited in Table 3.

TABLE 3.

Mean fat percentage at different ages

Age in years	Observed mean fat percentage	Calculated mean fat percentage
2	3.852	3.862
3	3.903	3.827
4	3.775	3.793
5	3.716	3.759
6	3.685	3.725
7	3.691	3.690
8	3.664	3.656
9	3.636	3.622
10	3.600	3.607
11	3.629	3.604
12	3.599	3.601
13	3.606	3.598
14	3.592	3.595
15	3.500	3.593
16	3.662	3.590

From an examination of the observed figures it appears that in general the fat percentage tends to decline with advancing years of age until the tenth year is reached. From that point on, allowing for chance fluctuations and the fact that the numbers dealt with get progressively smaller, the fat percentage appears to remain about constant for the rest of the cow's milking life. Consequently, it has seemed best to break the curve at the 10 year point and fit the two parts separately, each with a straight line. The resulting figures are given in the "calculated" column of Table 3. The equations to the two lines are as follows, the fitting having been done by the method of least squares.

From 2 to 10 years of age:

$$y = 3.896 - .0343x$$

From 10 to 16 years of age:

$$y = 3.610 - .0028x$$